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Proceedings of the 7th International Conference on Asian and Pacific Coasts (APAC 2013) Bali, Indonesia, September 24-26, 2013

EXPERIMENT STUDY ON PHYSICAL PROPERTIES AND MOTIONAL CHARACTERISTICS OF CORAL SAND

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ABSTRACT: Coral sand which mainly exist in tropical ocean environment is chemically composed of $CaCO_3$ and physically composed of debris and skeletal remains of coral reefs and marine lives under dynamic and weathering effects. Due to its particular material composition, particle structure, migration pathway and depositional environment, coral sand has different physical properties and motion characteristics with quartz sand. In this paper, the physical properties such as proportion, porosity, psephicity and fragmentation of coral sand were analyzed, and the motional characteristics in settlement and starting of coral sand were studied by physical model experiment using coral sand from Nansha islands as test material. The results showed that: (1) the physical properties of coral sand show as high grain density, high porosity, poor psephicity and high fragmentation; (2) water filling in the coral sand pore move with the coral sand itself; (3) coral sand particles with large proportion have a lower starting velocity than the calculation value considering the effect of water in the pore; (4) effective specific gravity controlled by the inner-pore volume should be consider in movement of coral sand.

Keywords: Coral sand, physical properties, movement characteristics, flume experiment, effective specific gravity.

INTRODUCTION

Coral island is special kind of bio-geomorphology which mainly exists in low-latitude tropical ocean environment. In recent years, coral reefs have been more and more important for ocean resources exploiting. Covering the coral island, coral sand is consists of hermatypic coral debris and biological bone debris.

It has developed into reef-flat facies or lagoon facies though onsite accumulation or short transportation driven by water and wind. The mineral contents are mostly aragonite and high magnesium the calcite with the calcium carbonate content up to 96 %. Determined by its sedimentary environment and components, coral sand is a unique rock and soil medium: loose, porous, and brittle.

It has quite different physical mechanical properties compared with the terrigenous quartz sand. Sediment erosion often appeared on coral reefs due to the improper consideration of the physical properties and motional characteristics of coral sand. The study of coral sand physical and motional properties has great significance to ocean resources exploiting.

In order to get better knowledge of the coral sand physical properties, mineral analysis, grain size analysis and porosity ratio and specific gravity measurement were done in the laboratory on the coral sand samples from the Nansha coral islets, and also sediment movement tests like setting test and flume experiment were made to get proper parameters for the protection of coral islands.

PHYSICAL PROPERTIES

Material Composition

Coral reef sand is mainly composed of hermatypic coral reef debris, and also includes other marine organism debris. Its mineral content is mainly aragonite and high magnesium calcite, and its chemical composition is $CaCO_3$. The grain size of coral reef varies, some reef block is above 5 mm, and some horn-shaped coral debris has high angularity, poor psephicity and high porosity. Grain size is related to the location landform unit, and becomes smaller gradually from outer reef flat to lagoon reflecting the effects of water force. Coral sand of outer reef flat facies is mainly composed of grave, with fine sand and medium sand between the gravels. Coral sand of inner reef flat facies is mainly coarse sand, and also has fine sand and medium sand. Lagoon coral sand is mostly the medium-fine sand.

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Specific Gravity

Generally, the specific gravity range of coral sand is 2.70~2.85g/cm^3, which is large than 2.65 g/cm^3 for quartz sand. Using pycnometer to get specific gravity of coral sand collected form Nansha Island, we have the specific gravity 2.82g/cm^3. During the test, it was noticed that the specific gravity is increased with the decrease of grain size. Table 1 shows the coral sand specific gravity around the world.

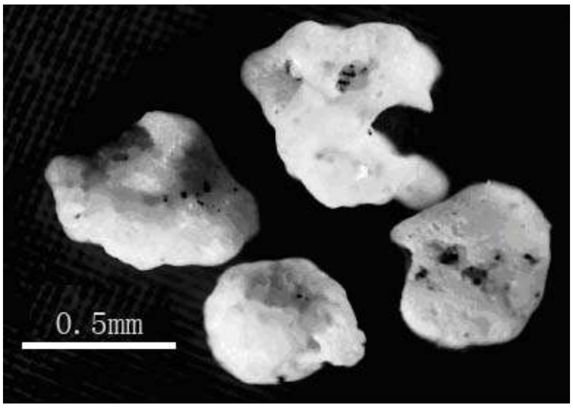
Porosity Ratio

Porosity ratio as an important index to evaluate the engineering properties of coral sand refers to the ratio of the volume of pores to that of solid particles. As to the coral sand, the pore volume includes two parts: the volume between the particles and that inside the particles. Experimental results show that the inner-pore volume of coral reef makes up about 10 % of the total volume, which reflects the coral sand itself is loose and polyporous. Experiment shows that inner-pore volume has close relationship to the shape of sand, the reason is that the coral sand is formed by in-situ accumulation or short-distance transportation, it has low psephicity and high angularity.

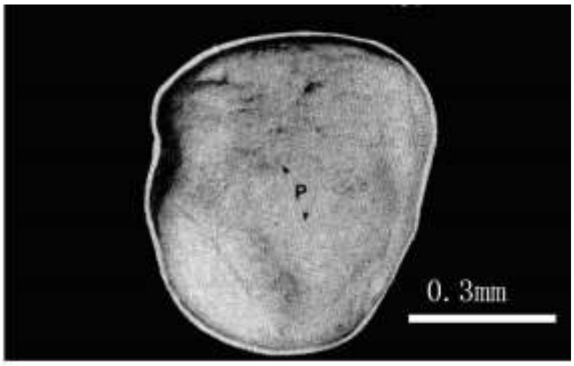
It is difficult to get the original coral sand samples, and also there is no empirical formula to calculate the relationship between the onsite data and the porosity ratio. In the test of maximum and minimum porosity ratio, the punching will change the grain size especially for the uneven grain size coral sand. A proper weight was put on the sand surface instead of punching to get a minimum porosity ratio. The porosity ratio of coral sand ranges from 0.54 - 2.97, much higher than that of quartz sand.

Table 1 The physical character of coral sand around the world

Place	Content of $CaCO_3$(%)	Specific gracity (g/cm^3)	Porosity ratio
Fiery Cross Island	96.7	2.73~2.80	0.75~1.26
The Xisha Islands	93~96	2.75~2.83	——
The Irish Sea	92.5	2.72	1.62~1.98
Western of India	75	2.80	0.75~1.07
Northwestern of Australia	94	2.72	1.22~1.92
Southeastern of Australia	88	2.73	0.54~1.01
Florida coast	92	2.80	1.00~2.97
The Nansha Islands	94	2.82	1.15~1.43



Coral sand



Quartz sand

Fig.1 Contrast of the shape and representational structure between coral sand and quartz sand

MOTIONAL CHARACTERISTICS

Setting Velocity

The setting velocity test of coral sand was done in the settler tube. Using the test sieve, the connected sand was divided into two different particle sizes, which their median particle sizes were 0.52mm, and 0.92mm. Under the condition of 15 degrees Celsius, the results showed in Table 2. Based on the formula (1), the setting velocity of coral sand and quartz sand were given in Table 2 either.

$$\omega = \left[\left(13.95\frac{\nu}{D}\right)^2 + 1.09\frac{\gamma_s-\gamma}{\gamma}gD\right]^{0.5} - 13.95\frac{\nu}{D} \qquad (1)$$

ω: setting velocity; ν: kinematic viscosity; D: grain size; γ_s: specific gravity of coral sand; γ_s: specific gravity of water.

Table 2 Setting velocity of coral sand

D(mm)	Coral sand		Quartz sand
	Test	Formula(1)	
0.30~0.84	5.5~11.1	4.3~11.2	4.0~10.6
0.60~2.00	6.5~14.6	8.9~19.1	8.2~18.1

The results show that the fine coral sand has larger setting velocity then quartz sand with the same size, and it was opposite for coarse particle because of the low prephicity and high porosity ratio.

Starting Velocity

Flume experiment

The incipient velocity test was done in the flume with the size of 50m×0.8m×1.0m, which could simulation the current, Under the condition of water depth 0.6m, the max current velocity and wave height can up to 0.5m/s and 0.25m.

In order to research the incipient velocity influenced by water depth and grain size, series experiments were done in different water depth. The grain size included the natural size (D_{50}=0.64mm) which was collected in Nansha, and screening from natural sand to fine sand(D_{50}=0.52mm) and coarse size(D_{50}=0.92mm). Water depth as 0.1m, 0.2m, 0.3m, 0.4m and 0.6m were chosen in the test.

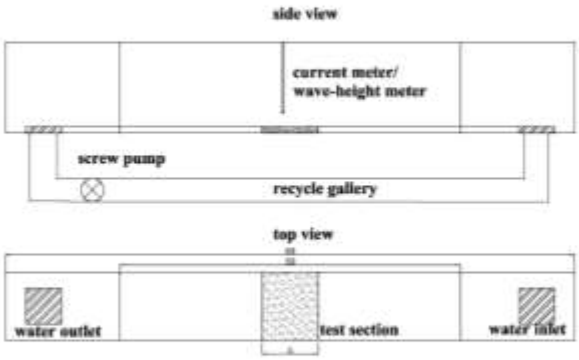


Fig.2 The diagram of experiment flume (m)

Analysis of experiment results

The results were shown in Fig.3 and Table 3. It's observed that the starting velocity increased as the water depth and grain size. When depth in flume is 10cm, the minimum starting velocity is 0.284m/s. There was little difference between 0.52mm and 0.64mm.

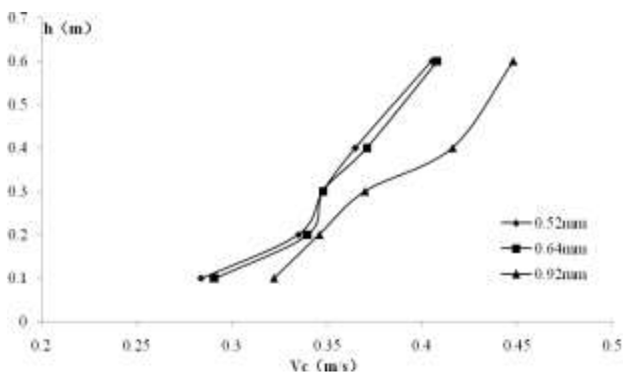


Fig.3 Starting velocity in different water depth and different grain size

Table 3 Starting velocity of coral sand

D_{50}(mm)	Water Depth(m)	Starting Velocity(m/s)
	0.1	0.284
	0.2	0.335
0.52	0.3	0.348
	0.4	0.365
	0.6	0.405
	0.1	0.291
	0.2	0.340
0.64	0.3	0.348
	0.4	0.371
	0.6	0.408
	0.1	0.322
	0.2	0.346
0.94	0.3	0.370
	0.4	0.416
	0.6	0.448

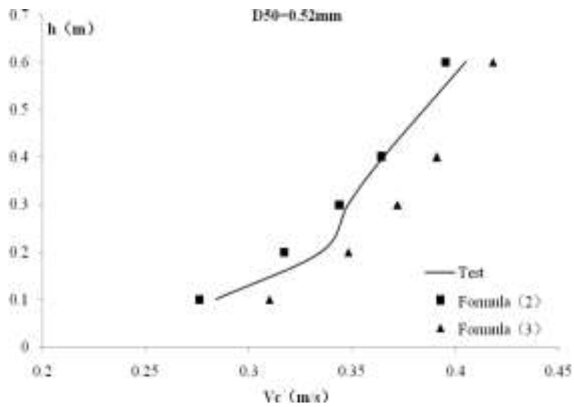
Furthermore, on the basis of empirical formula (2) and (3), the calculated results were compared with which from flume experiment.

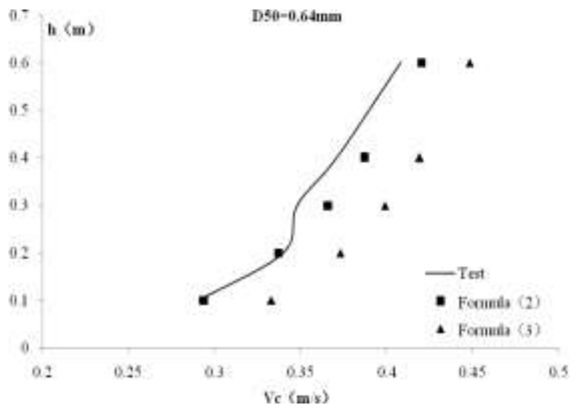
$$V_c = 1.34\left(h/D\right)^{0.14}\sqrt{\left(\gamma_s-\gamma\right)gD/\gamma} \tag{2}$$

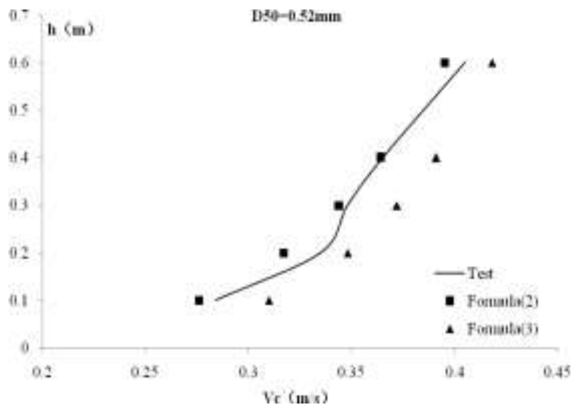
$$V_c = \left(h/D\right)^{\frac{1}{5}}\sqrt{\left(\gamma_s-\gamma\right)gD/\gamma} \tag{3}$$

V_c: starting velocity; h: water depth; formula(3) used in the condition that $D \geq 0.24\text{mm}$.

As shown in Fig.3, the starting velocity data got from flume experiment is compared with the calculated results by empirical formula. From the series test of D_{50}=0.52mm, the expression can describe the experiment well. But with the diameter increasing, the gap increased as well as the grain size. For D_{50}=0.64mm, the differential was -1%~15% with average value 7%. And for D_{50}=0.92mm, the differential was 2%~22% with average value 12%.







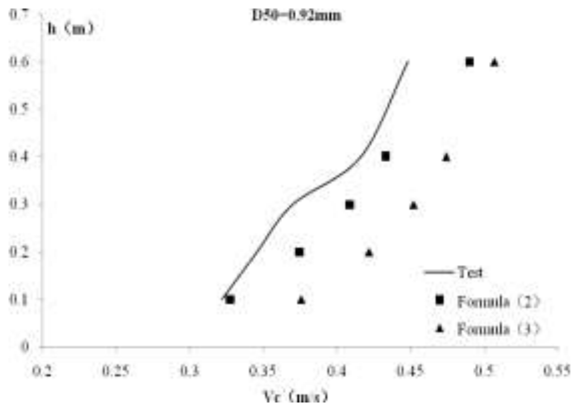


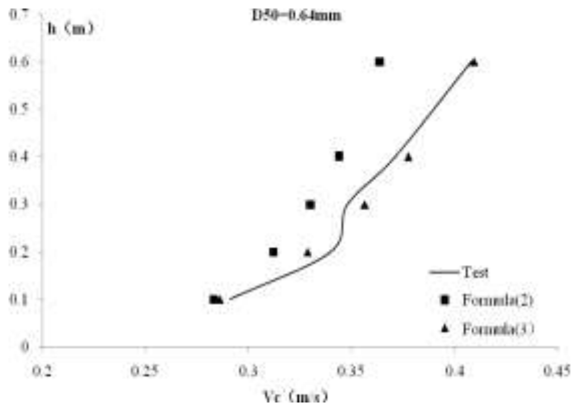
Fig.4 Compare the result between test and empirical formulas

Effective Specific Gravity

As mentioned above, existed in coral sand, the inner-pore volume is filled with water in commonly. As the sediment motioned under wave and current condition, the water in the volume either moved as one part of the sand. Therefore, it should be considered as a whole in the motional characteristics analysis. In this situation, the whole specific gravity can be defined as effective specific gravity (γ_e).

In this paper, the inner-pore volume for D_{50}=0.64mm and D_{50}=0.92mm sand were supposed to be 5% and 10%. Based on the definition and hypothesis, the effective specific gravity would be 2.73g/cm^3 and 2.64g/cm^3. Fig.5 showed the compare as γ_e replaced γ_s in formula 2 and 3.

The results indicated that the calculated values are match well with test data. For D_{50}=0.64mm, the differential was -11%~2% with average value -3%. And for D_{50}=0.92mm, the differential was -10%~5% with average value -2%.



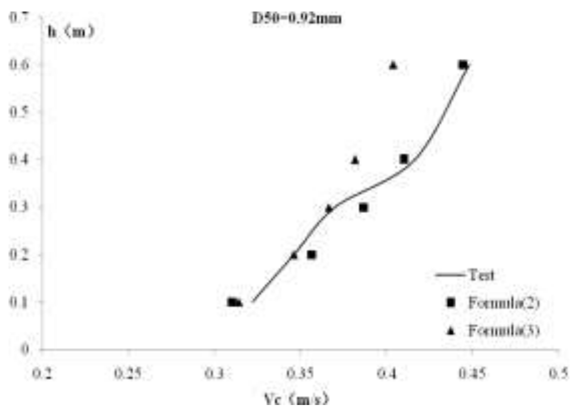


Fig.5 The calculated results in effective specific gravity

CONCLUSIONS

As a special marine soil medium, coral sand shows different mechanic properties compared to quartz sand:

(1) the physical properties of coral sand show as high grain density, high porosity, poor psephicity and high fragmentation;

(2) water filling in the coral sand pore move with the coral sand itself;

(3) coral sand particles with large proportion have a lower starting velocity than the calculation value considering the effect of water in the pore.

(4) effective specific gravity controlled by the inner-pore volume should be consider in movement of coral sand.

ACKNOWLEDGEMENTS

This research was partially supported by the NHRI Science Foundation under Grant Y213006 and by the Key Laboratory of Port, Waterway & Sedimentation Engineering, Ministry of Communications, PRC.

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